National Aeronautics and Space Administration

Recent Advancements in Modeling and Simulation of Entry Systems at NASA

Michael Barnhardt, Aaron Brandis
Michael Wright, Monica Hughes

2019 IEEE Aerospace Conference | 03.06.19

EDL Modeling & Simulation at NASA

Investments span multiple directorates, programs, and projects

- **Human Exploration and Operations**
  - Orion MPCV
- **Science**
  - MSL/MEDLI and Mars 2020/MEDLI2
  - Mars Sample Return
- **Aeronautics Research**
  - Limited overlap with Transformational Tools and Technology (TTT) and Hypersonics Technology Project (HTP)
- **Space Technology**
  - Heatshield for Extreme Entry Environment Technology (HEEET)
  - Adaptable Deployable Entry and Placement Technology (ADEPT)
  - Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)
  - Advanced Supersonic Parachute Inflation Research Experiment (ASPIRE)
  - Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE)
  - Descent Systems Study (DSS)
  - Pterodactyl
  - Entry Systems Modeling (ESM)
  - Space Technology Research Grants (STRG)
- **NASA Engineering and Safety Center**
  - Several focused, short-term activities and grants

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Entry Systems Modeling Project

- **Modeling & Simulation is critical path for EDL, in every mission phase, with a reach extending beyond NASA**
- **The Entry Systems Modeling Project (ESM) is focused on delivering real advancements to the current SoA that impact NASA missions**
  - Mid-TRL R&D, with topic areas driven by mission needs
  - Establish a "pipeline" to fundamental research via creative partnerships within NASA, OGAs, and academia to leverage the best new and innovative ideas
    - Over 100 academics (students & faculty) involved each year via multiple funding mechanisms
    - Multiple international partnerships supported (DLR, JAXA, UQ, VKI, CentraleSupelec)
  - Mature new capabilities and prepare them for mission infusion; products handed to missions and line organizations for application and stewardship
    - Long-term maintenance and support is out of scope; remains a significant challenge for the Agency

> *"For complex missions that cannot be fully tested on Earth, we rely on computer models to convince ourselves that the integrated system will work in its intended environment. We have no other way to do this. Detailed subsystem hardware and software testing help us validate that each of these models do a good job of representing reality."*
>
> **-- Rob Manning, Mars Program Chief Engineer**

Space Technology Portfolio/Pipeline

Early Stage
- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund

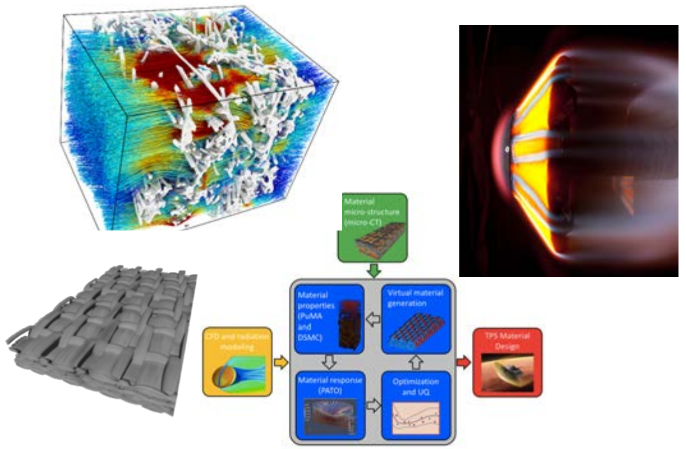
Commercial Partnerships
- SBIR /STTR
- Flight Opportunities
- Centennial Challenges
- Regional Economic Development

TECHNOLOGY PIPELINE

Entry Systems Modeling:
Core Investment Areas

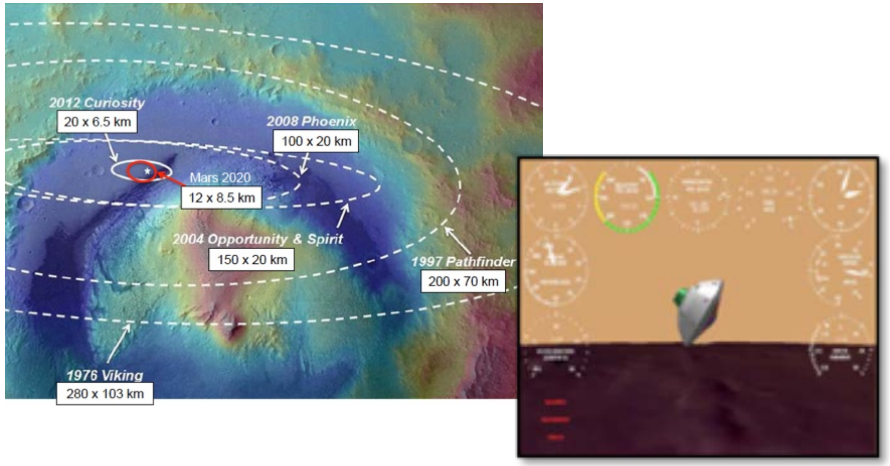
Predictive Materials Modeling

Advanced models for PICA and woven TPS; Micro- to engineering-scale analysis tools; Detailed material characterization and model validation



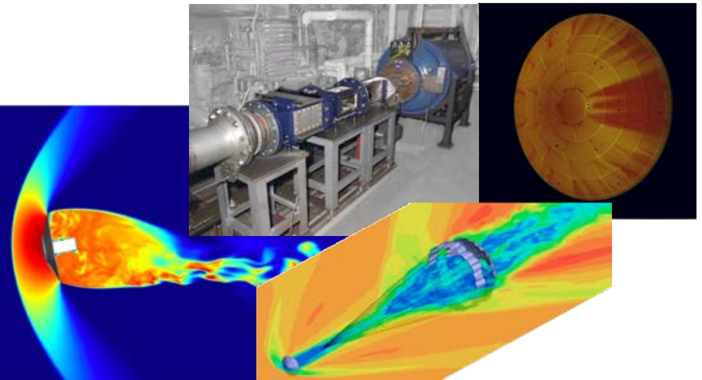
Guidance, Navigation, and Control

Entry guidance methods to enable precision landing of large robotic and human Mars missions



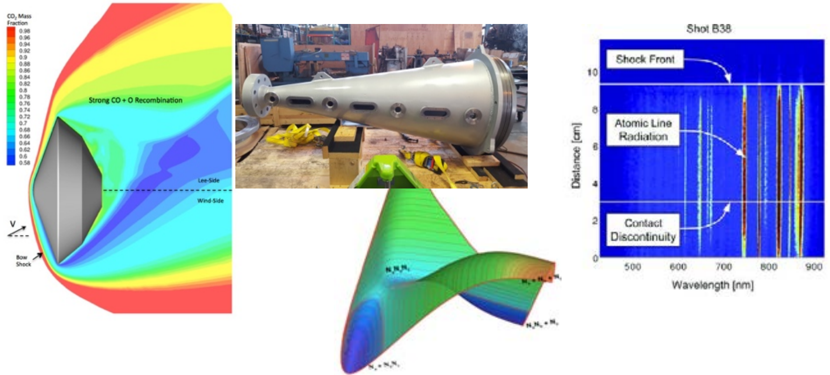
Aerosciences

Parachute dynamics; Free-flight CFD; Magnetic suspension wind tunnels; Experimental validation; Roughness, Advanced computational methods



Shock Layer Kinetics and Radiation

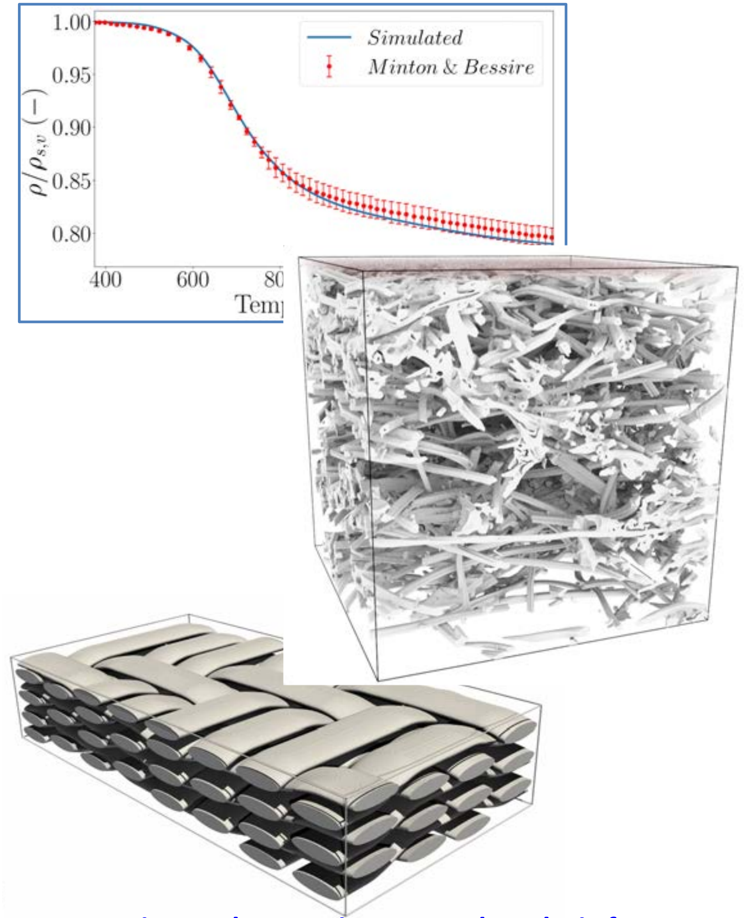
Radiation databases and models for all destinations of interest; High-fidelity analysis tools, coupled analysis



Predictive Material Modeling

Microscale

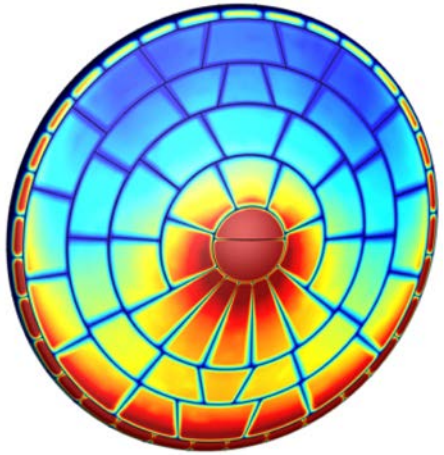
Lead: Nagi Mansour (NASA)

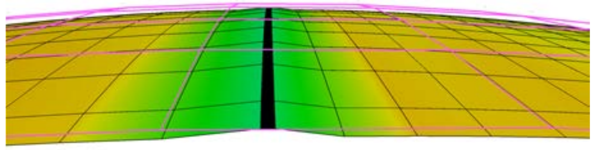


Microscale experiments and analysis for fundamental properties, validation

Benchmark Modeling

Lead: Nagi Mansour (NASA)



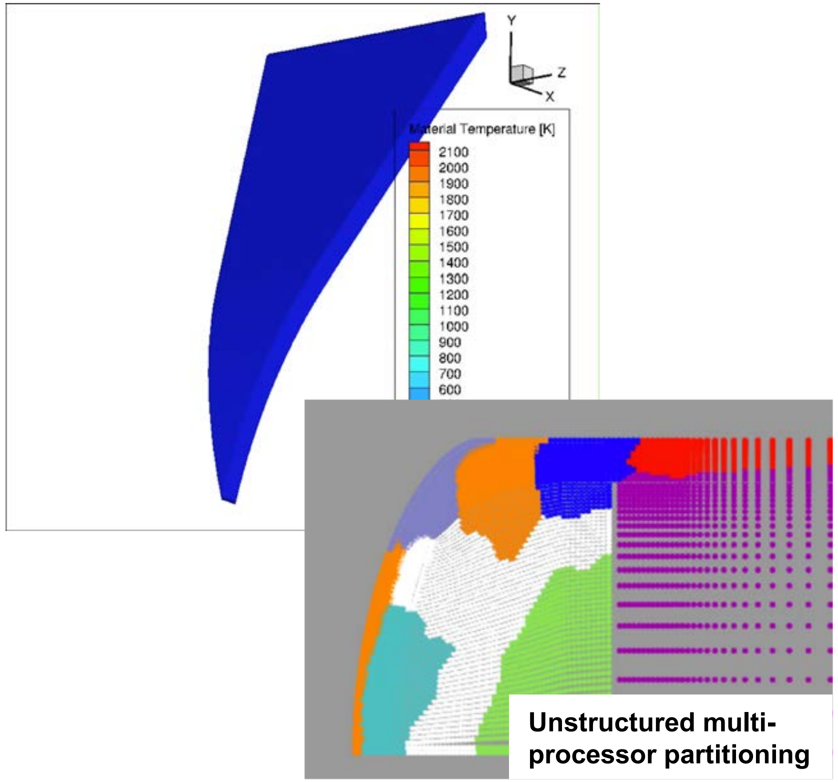


Gap filler

Benchmark simulations with PATO software to aid model development and quantify uncertainty

Engineering Applications

Lead: Eric Stern (NASA)



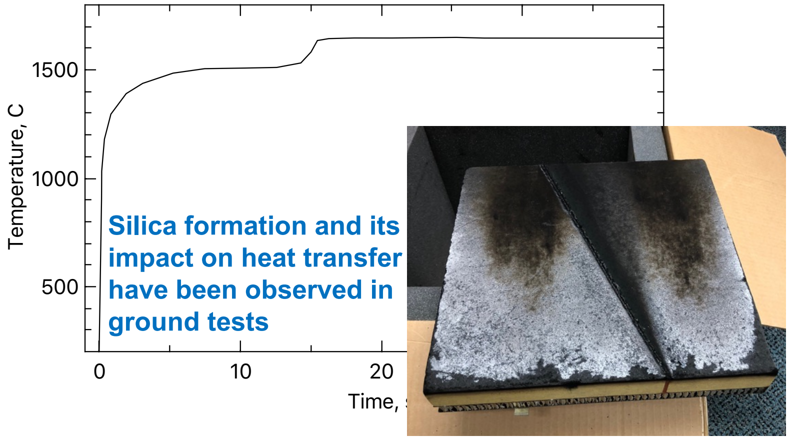
Rapid 3-D simulations of TPS and substructure using Icarus, a parallel, scalable software

PICA-NuSil

Leads: Brody Bessire (NASA), Nagi Mansour (NASA), Francesco Panerai (Illinois)

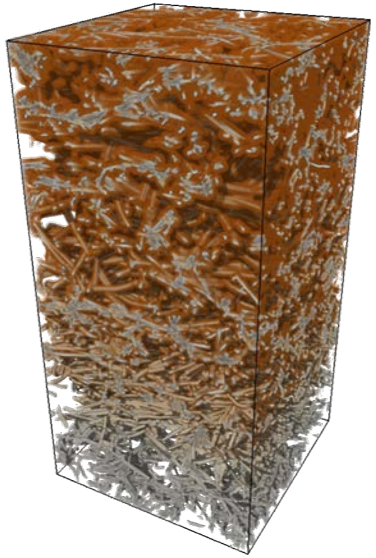
Silicone (NuSil) coating on MSL and Mars 2020 significantly impacts our interpretation of flight measurements

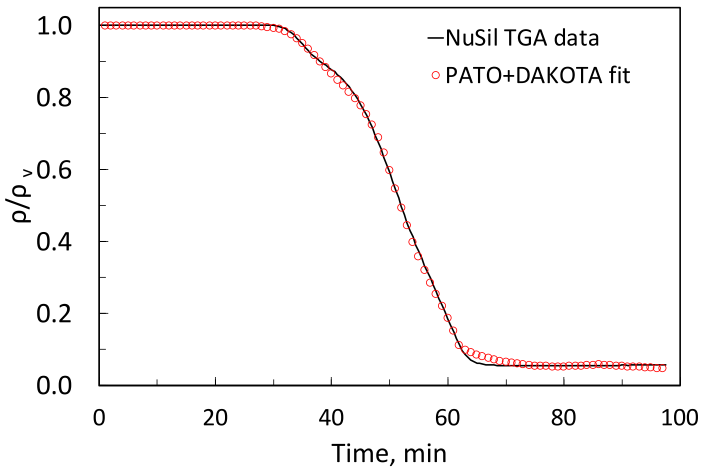
- **Silica coating has low catalycity and acts as an oxidation barrier**
- **It could also impair the transport of pyrolysis gas into boundary layer**



High Fidelity Model

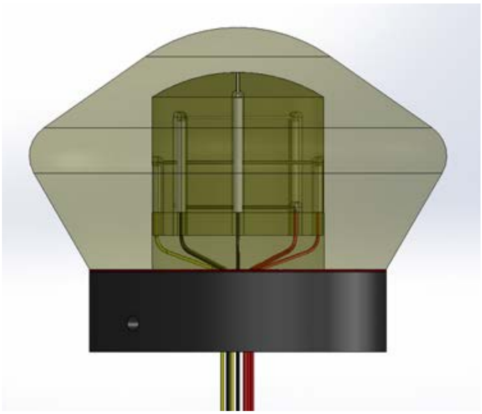
- **PICA-N material properties database**
- **Finite-rate gas/surface interaction model**
- **Detailed simulation capabilities**

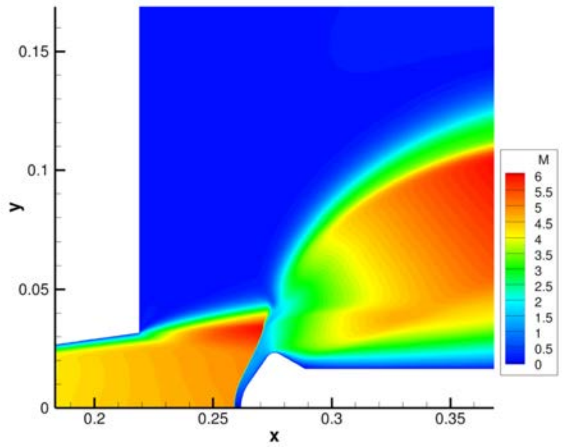




Material Response Validation Data

- **Design and execution of arc-jet test campaigns**

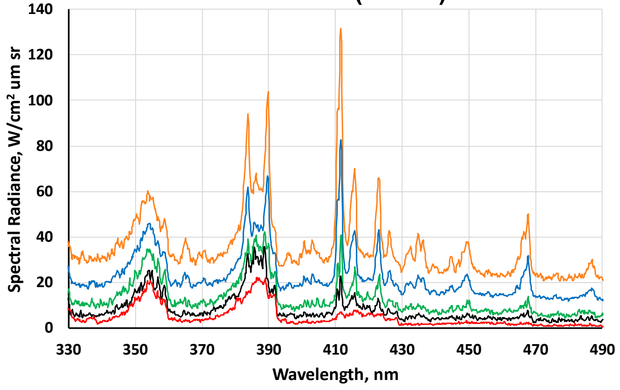


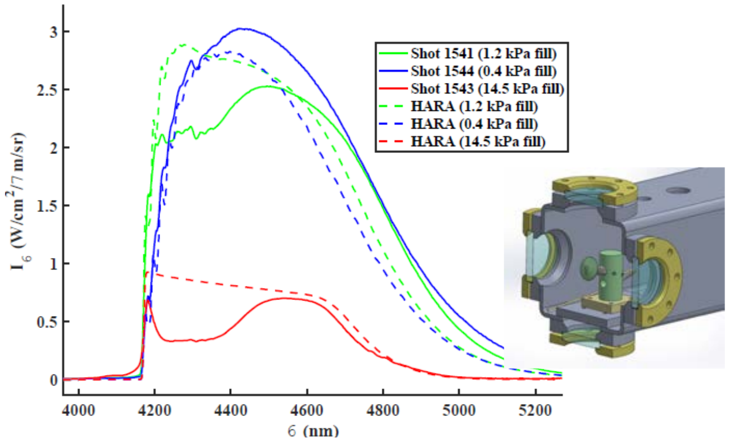


Shock Layer Kinetics and Radiation

Experiments

Lead: Brett Cruden (NASA)

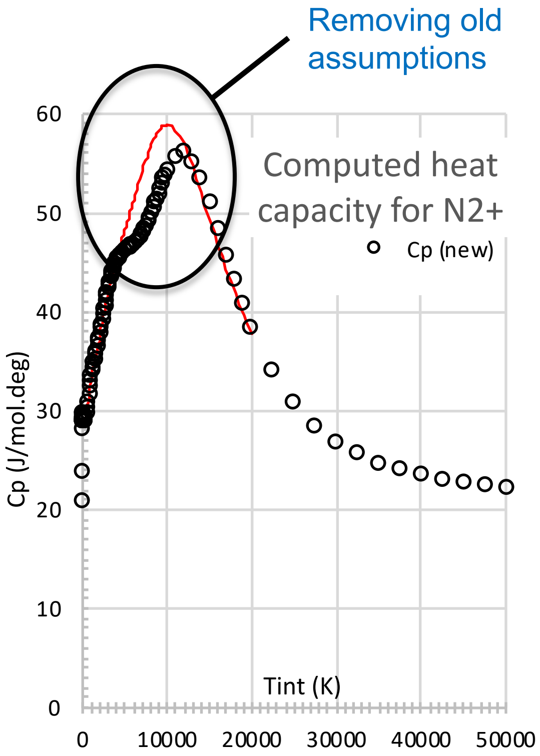




Spectral radiance measurements in EAST (top) and CalTech tunnel (Bottom) provide crucial data for model development and validation.

Computational Chemistry

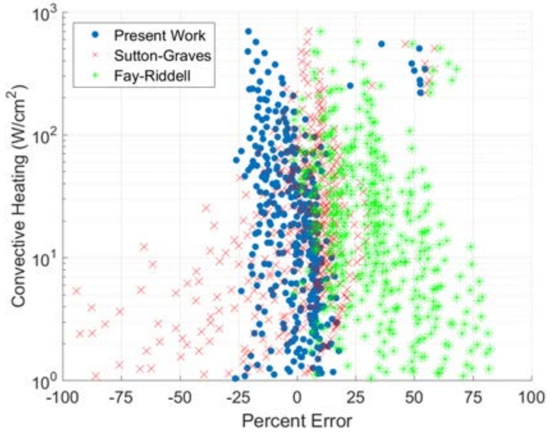
Lead: Rich Jaffe (NASA)

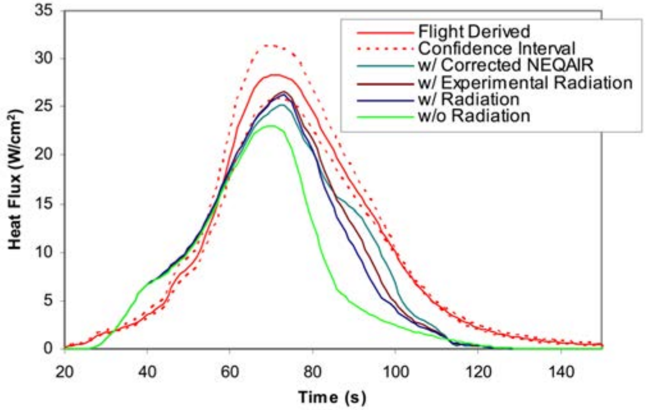


Many CFD model parameters are inaccessible experimentally. Advancements in computational chemistry enable us to determine parameters with high precision.

Applications

Leads: Aaron Brandis (NASA), Chris Johnston (NASA)





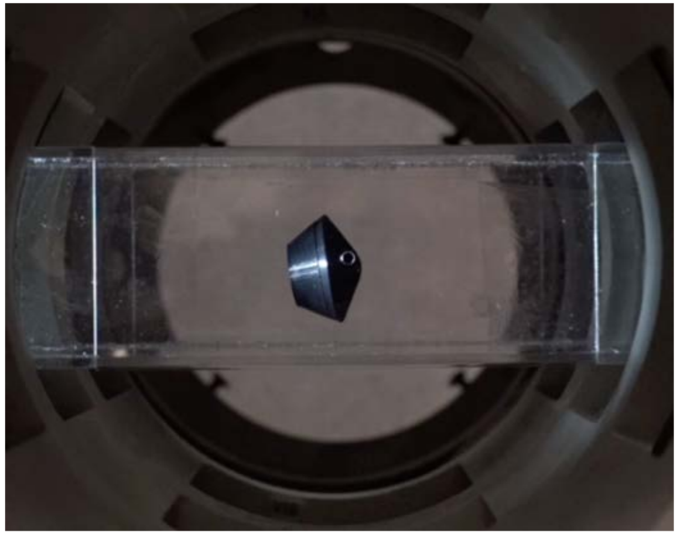
Top: Convective heating correlations for Mars entries
Bottom: Flight data from Mars Science Laboratory strongly suggests CO2 radiation as a significant contributor to vehicle heating

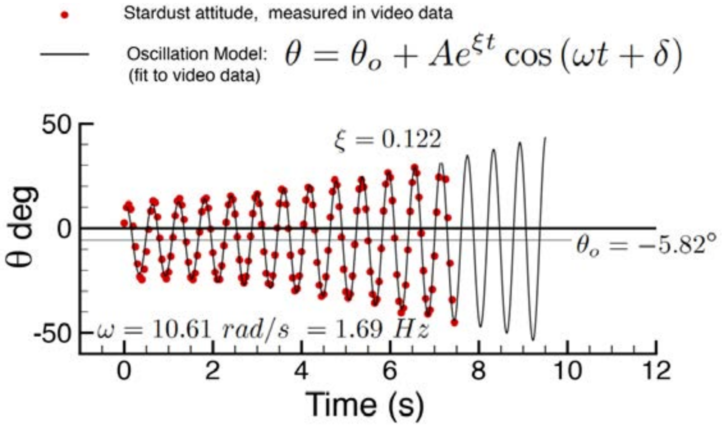
Computational & Experimental Aerosciences

Entry Vehicle Dynamics

Magnetic Suspension Wind Tunnel

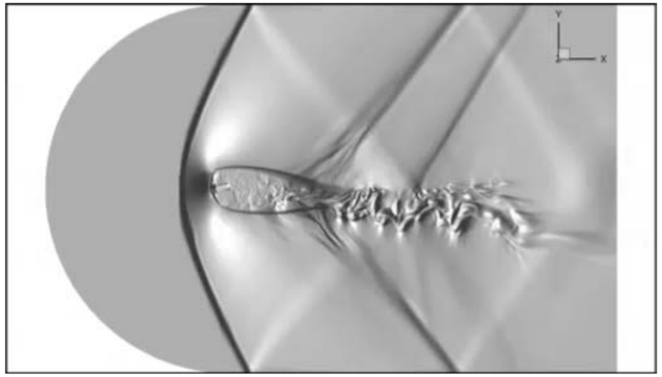
Lead: Mark Schoenenberger (NASA)

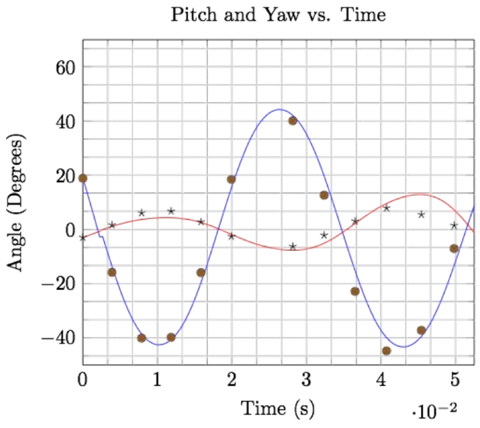




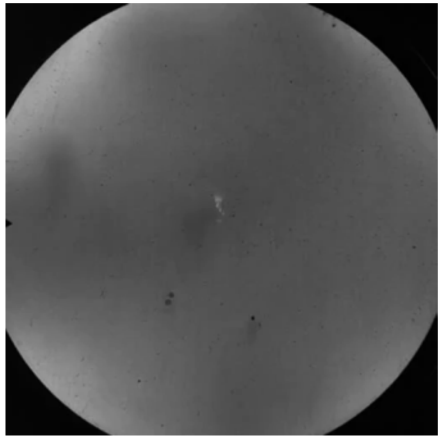
Free-flight CFD

Lead: Joe Brock (NASA), Eric Stern (NASA, ATAP)

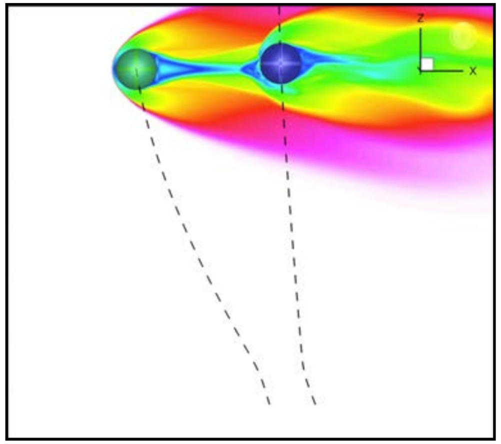




Multi-body aero collaboration with Asteroid Threat Assessment Project (ATAP)



German Aerospace Center Tunnel



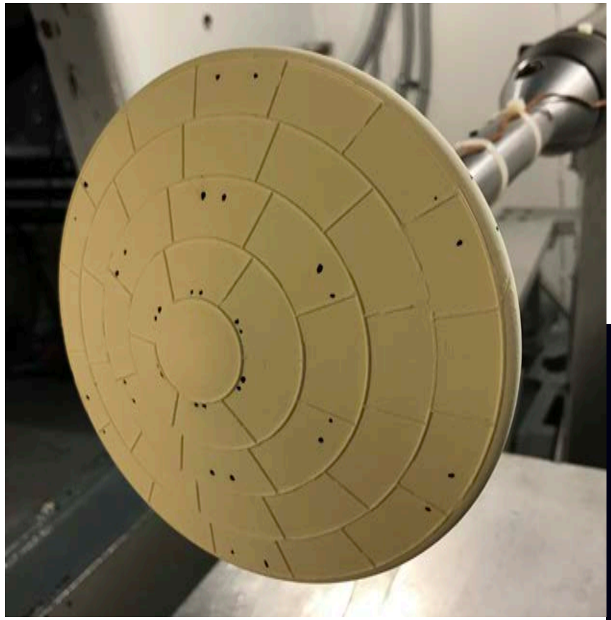
Simulated Comparison

Computational & Experimental Aerosciences

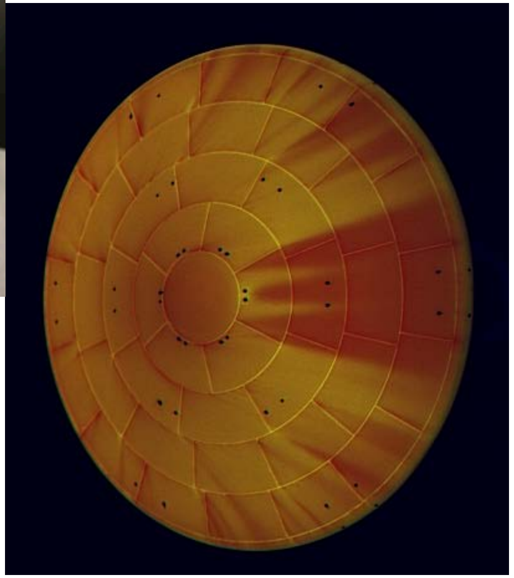
Turbulent and Transitional Heating

Block TPS Roughness

Lead: Brian Hollis (NASA)

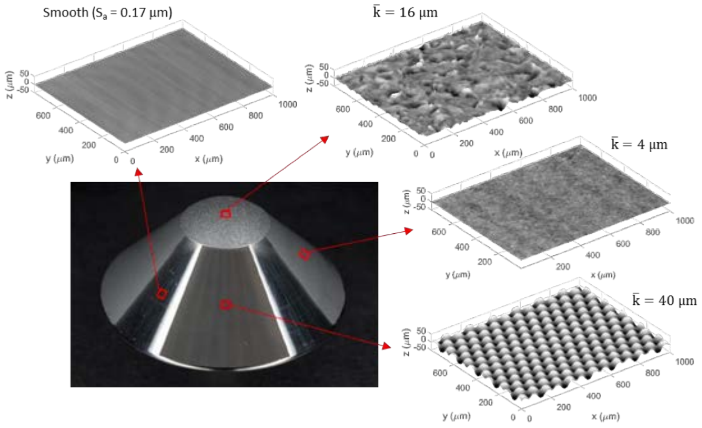


Phosphor-coated ceramic block TPS model and representative heating augmentation during test



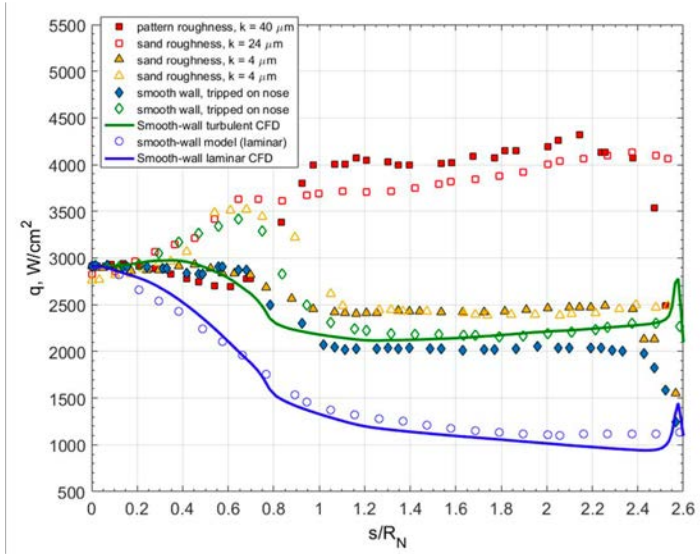
Woven TPS Roughness

Lead: Mike Wilder (NASA)



Model laser-etched with smooth, sand-grain, and woven roughness patterns.

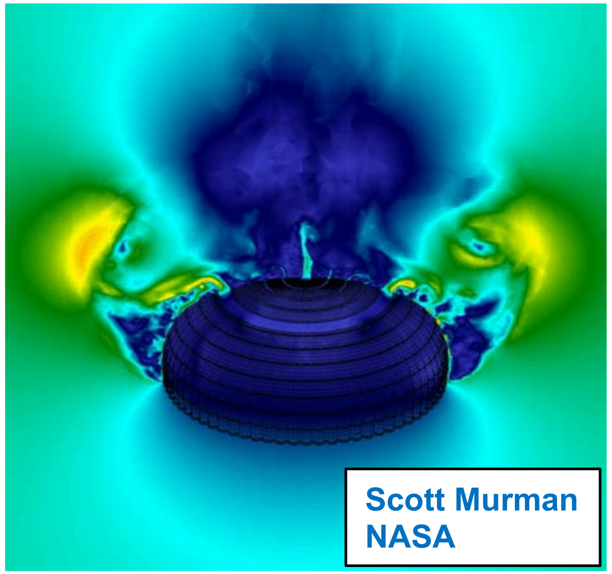
Woven pattern is less efficient at heating surface than sand-grain roughness.



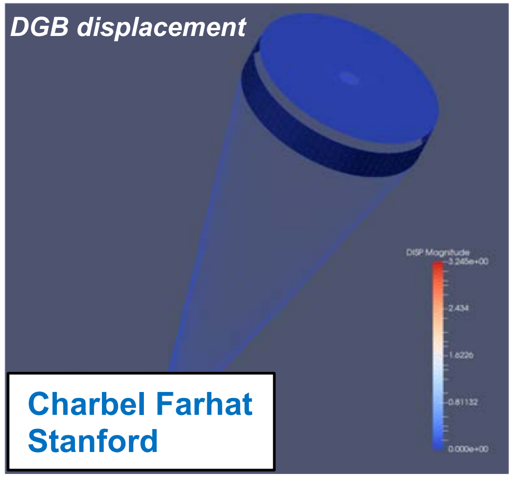
Computational & Experimental Aerosciences

Parachute Descent and Inflation Dynamics

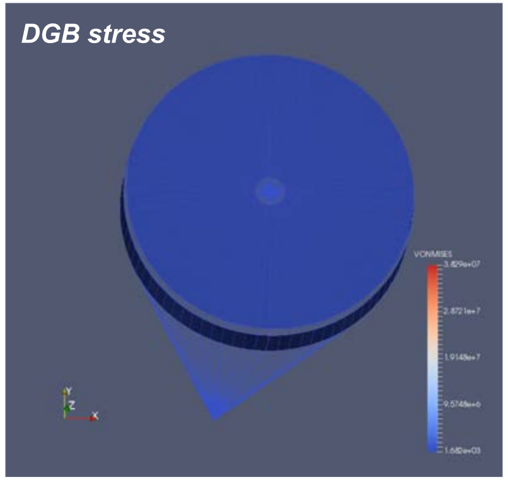
First demonstration of high-order canopy simulation for analyzing descent dynamics.

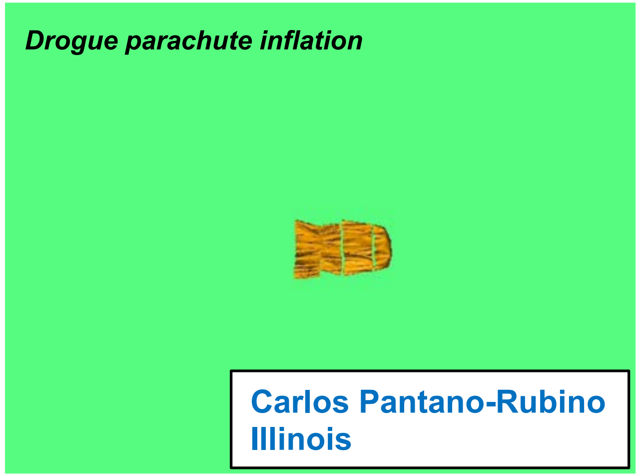


Scott Murman
NASA



Charbel Farhat
Stanford





Carlos Pantano-Rubino
Illinois

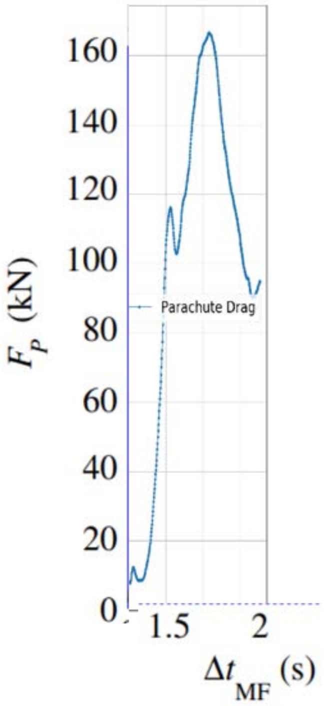
STRG-funded academic partners making excellent progress on parachute inflation.

Computational & Experimental Aerosciences

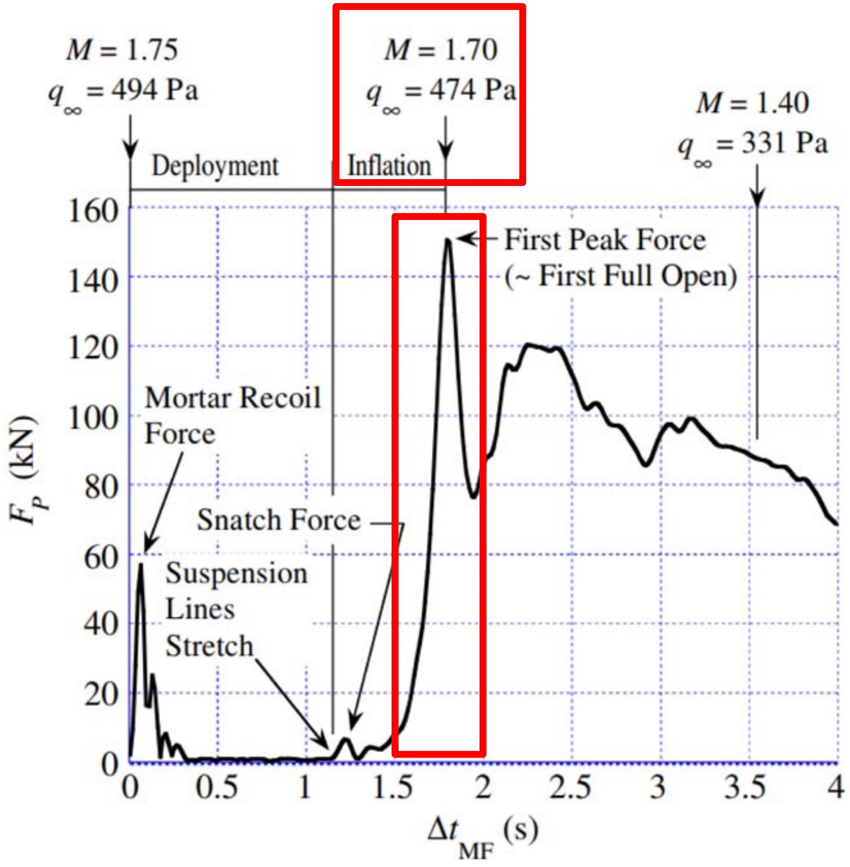
Parachute Descent and Inflation Dynamics

Preliminary comparison of predicted and flight (MSL) snatch load

Credit: Charbel Farhat (Stanford)



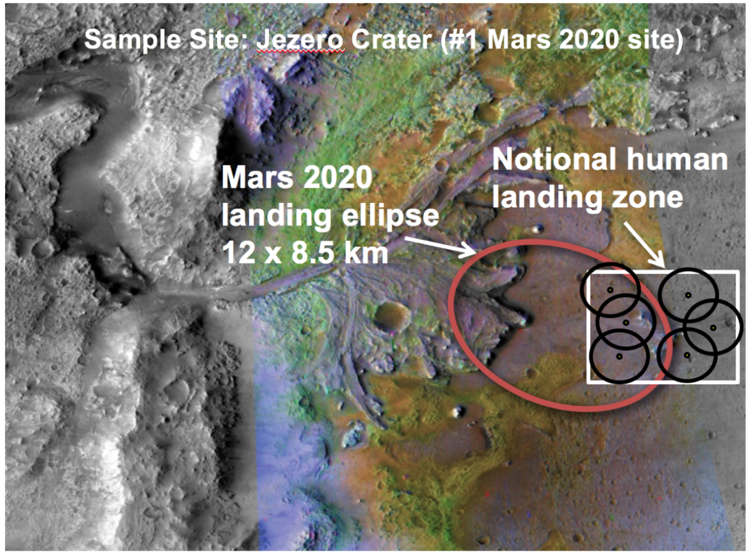
AERO Suite

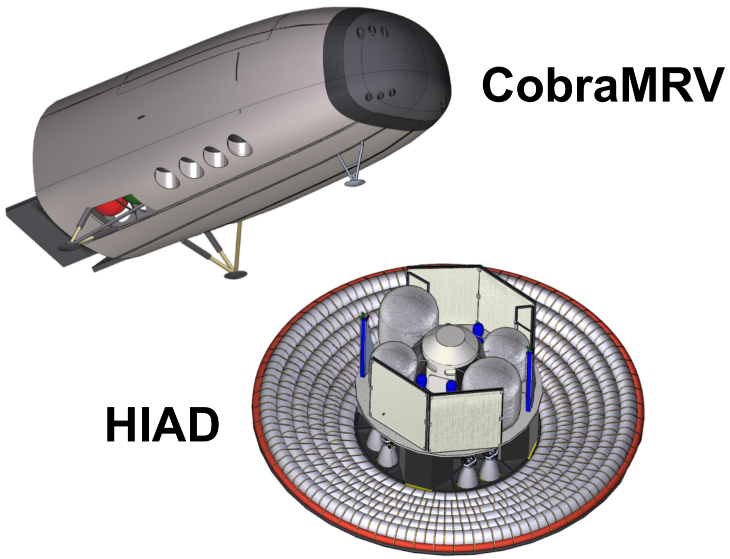


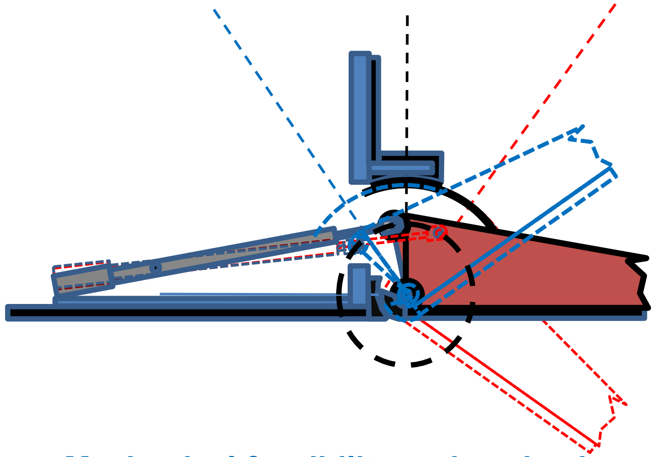
Test Data

Guidance, Navigation & Control

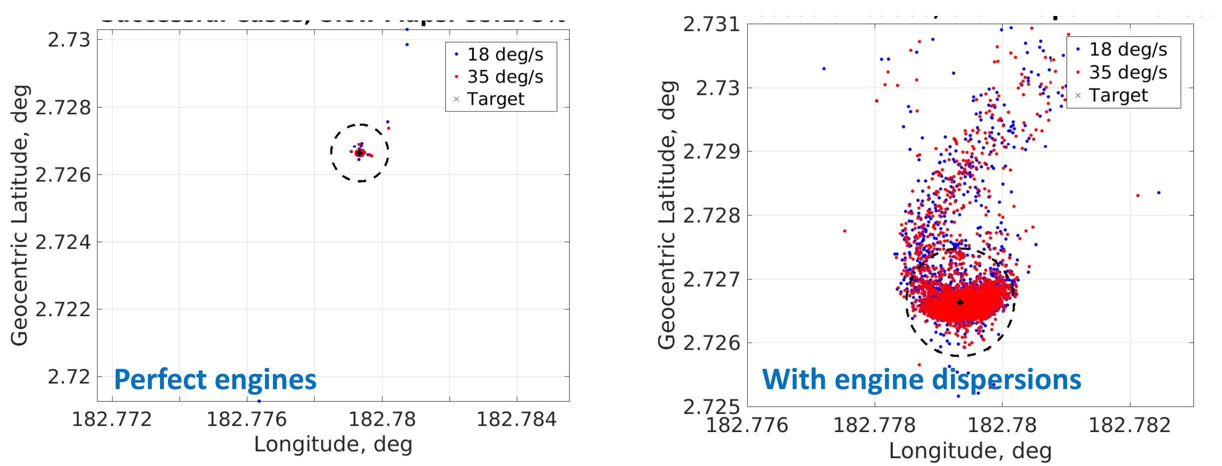
Lead: Alicia Dwyer-Cianciolo (NASA)



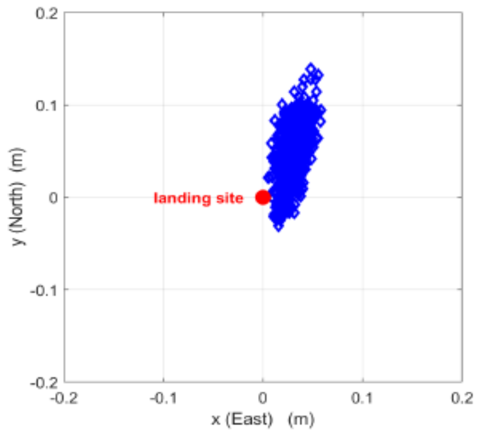




Mechanical feasibility and packaging



Landing Precision of HIAD w/Flaps



Landing Precision of CobraMRV

We Need Your Help

…in order to keep ahead of tomorrow's challenges.

If you have insight into pressing mission needs or ideas on how to address them, we would love to hear from you:

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BACKUP